Embedded Software: Opportunities and Challenges

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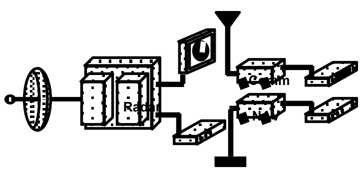
Embedded Software: Depth of Impact

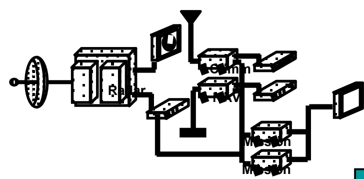
Evolution of Avionics Systems:



Independent Avionics — 64 KB

DEDICATED SUBSYSTEMS

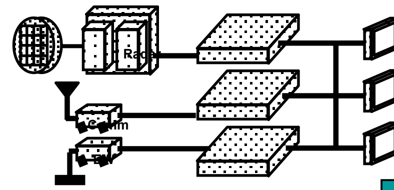
- Digital Fire Control/NAV
- PT-PT Wiring
- Mechanically Controlled Sensors/FLT Controls/ Displays
- Crew-Dominated Operation



Federated Avionics — 1 MB

FEDERATED SUBSYSTEMS

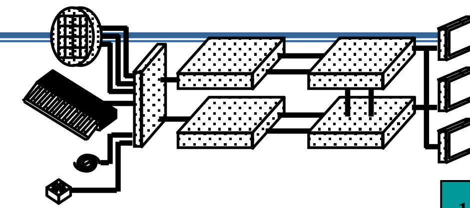
- Functionally Integrated Data Processing
  - -NAV/WD/Air Data Sensors
  - -Flight Control
- Beam Steering Sensors
- Fly By Wire
- Dedicated Digital Processing
- Crew-Assisted Operations
  - Weapon Delivery
  - Automated TF/TA
  - EW Response



Integrated Avionics — 100 MB

INTEGRATED SYSTEMS

- **Aircraft-Wide Information Integration**
  - Sensors/Stores/ Vehicle/ Propulsion
- Modular Electronics
- Massive Data Bases
  - Terrain, Threat
- Digital Sensor Processing
  - Sensor Fusion
  - Hyperspectral Imaging
- Integrated Diagnostics/ System Fault Tolerance
- System Data Security
- Limited UAV Autonomy



Advanced Avionics — 1 GB

SYSTEM of SYSTEMS

- Platform Exploitation of Global Information
  - Information Mining
  - At-A-Distance Reconfiguration
- Autonomous Vehicle Emphasis
  - Air & Space
- Air Crew/ Ground Crew Monitoring & Management
- Automated Functions
  - ATR (Multi-Sensor)
  - Failure Prognostics
  - Route/ Sensor/ Weapon/ Vehicle Coordination
  - Bistatic Sensing (Air/ Space)
  - Threat Evasion

1958 | 1950's - 60's | 1970's - 80's | 1990's - 00's | 2000 →

Source: AFRL

Embedded Software: Breadth of Impact

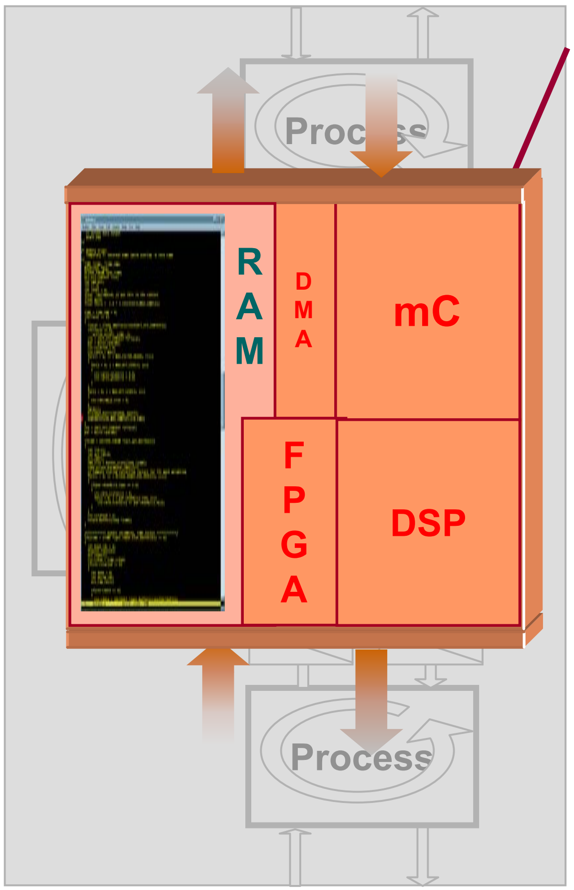
- ***DoD (from avionics to micro-robots)***
  - *Essential source of new capabilities*
  - *Largest, most complex systems*
- ***Automotive (drive-by-wire)***
  - *Key competitive element in the future*
  - *Increasing interest but low risk taking*
- ***Consumer Electronics (from mobile phones to TVs)***
  - *Problem is generally simpler*
  - *US industry is strongly challenged*
- ***Plant Automation Systems***
  - *Limited market growth, conservative approach*

Overview

Impacts / Unique Challenges	Development Environments			Execution Frameworks
	Representation	**Verification and Validation**	**Synthesis and Generation**	
Physicality	**Languages** System-Level Modeling - Domain Specific - Aspect-Oriented	**Integrated Modeling** - Hybrid modeling - Model integration	**Generative Programming** - Model-based - Multi-target - Meta-generators	**Models of Computation** - RT support for hybrid MOC-s - Integrated software/system frameworks
Constrains and Change	**Modeling Tools** - Meta-programmable - Consistency management	**Analysis, Synthesis and Application Generation** - New hybrid analysis - Constraint-based synthesis - Open tool integration frameworks		**Adaptive execution frameworks, middleware** - Decoupling via over-design - Embeddable synthesis and generation - Reflection and runtime adaptation - Probabilistic models
Variable Structure	**Design Frameworks** - Property guarantees by frameworks - Orthogonalization by over-design		**Framework Composition** - Middleware for coordination - Customization	

Theme 1: Physicality

Embedded software: defines physical behavior of a complex nonlinear device



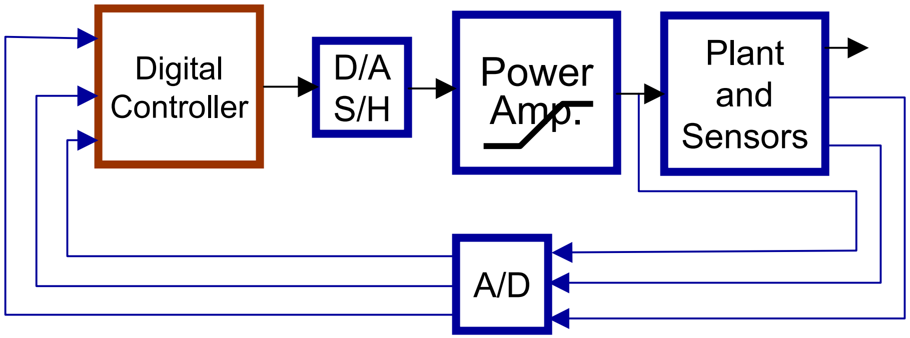
Embedded System: a physical process with dynamic, fault, noise, reliability, power, size characteristics

Embedded Software: designed to meet required physical characteristics

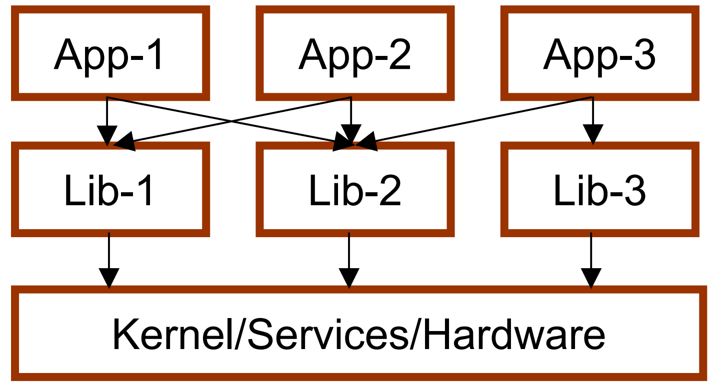
Primary challenge: How to design software to achieve required physical behavior?

Interactions, interactions,…

Controller Dynamics



Embedded Software



- control law
- tolerated error, stability
- sampling rate

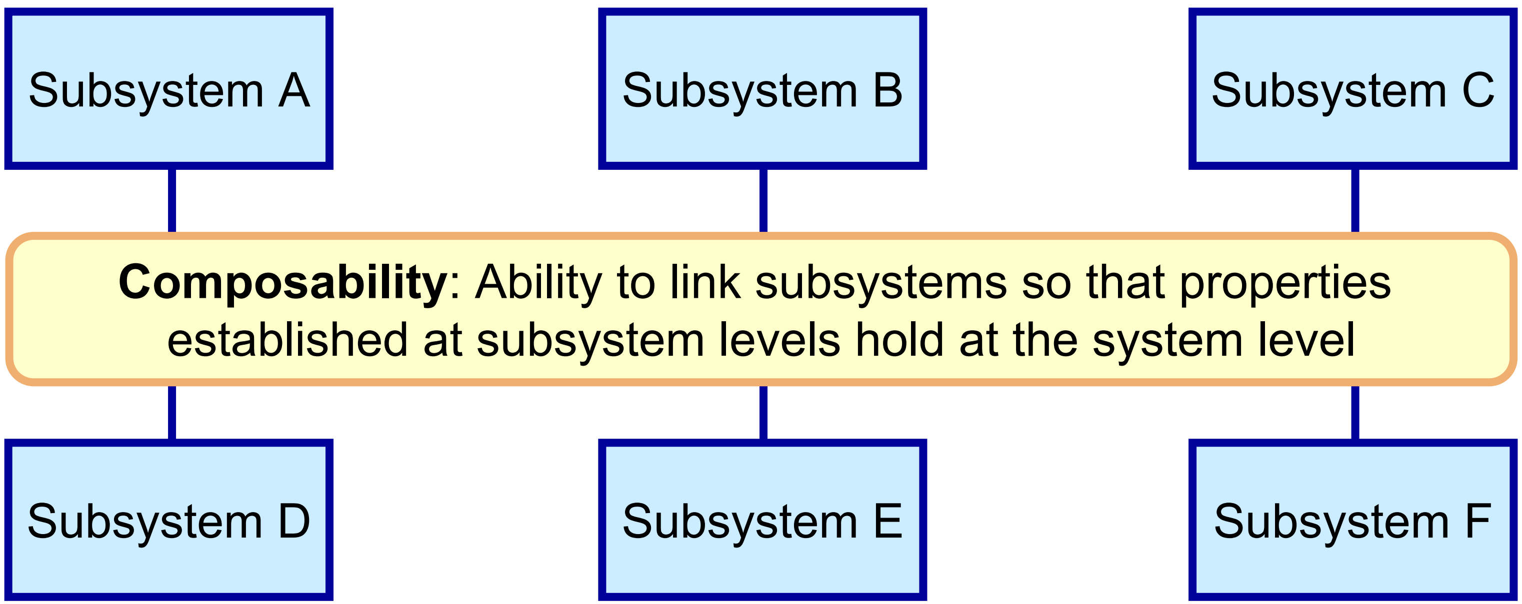
- limit-cycle oscillation
- loop delay
- noise

- HW/SW architecture
- Data types selection
- Scheduling policy,…

- Numeric accuracy
- Latency
- Jitter

Why Is this a Problem?

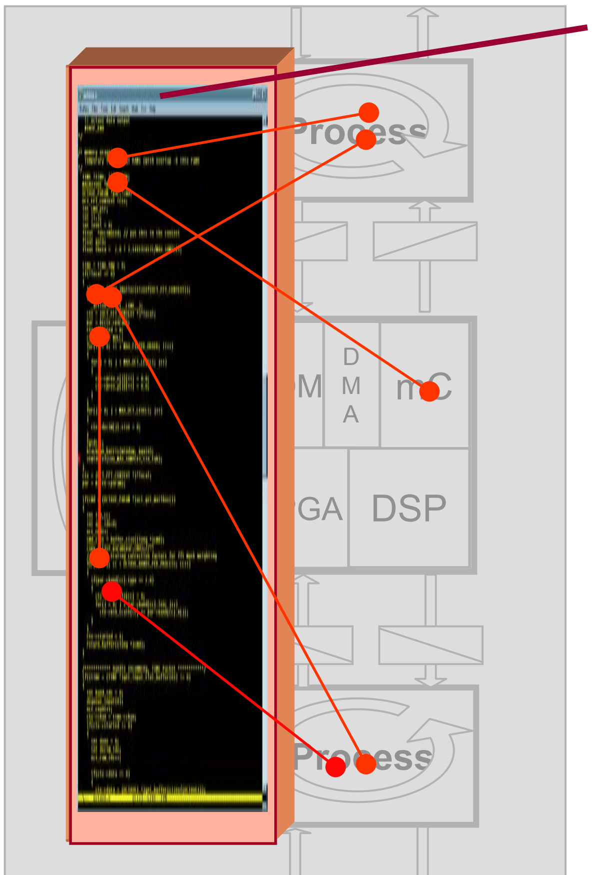
We have focused on functional composition...



But cross-cutting physical constraints weaken or destroy composability

Theme 2: Constraints and Change

Source of change: environment, requirements



Hard Problem: system-wide constraints accumulate in software

Effects of changes need to propagated by tracking constraints

Flexibility is essentially a SYSTEM-WIDE CONSTRAINT MANAGEMENT PROBLEM

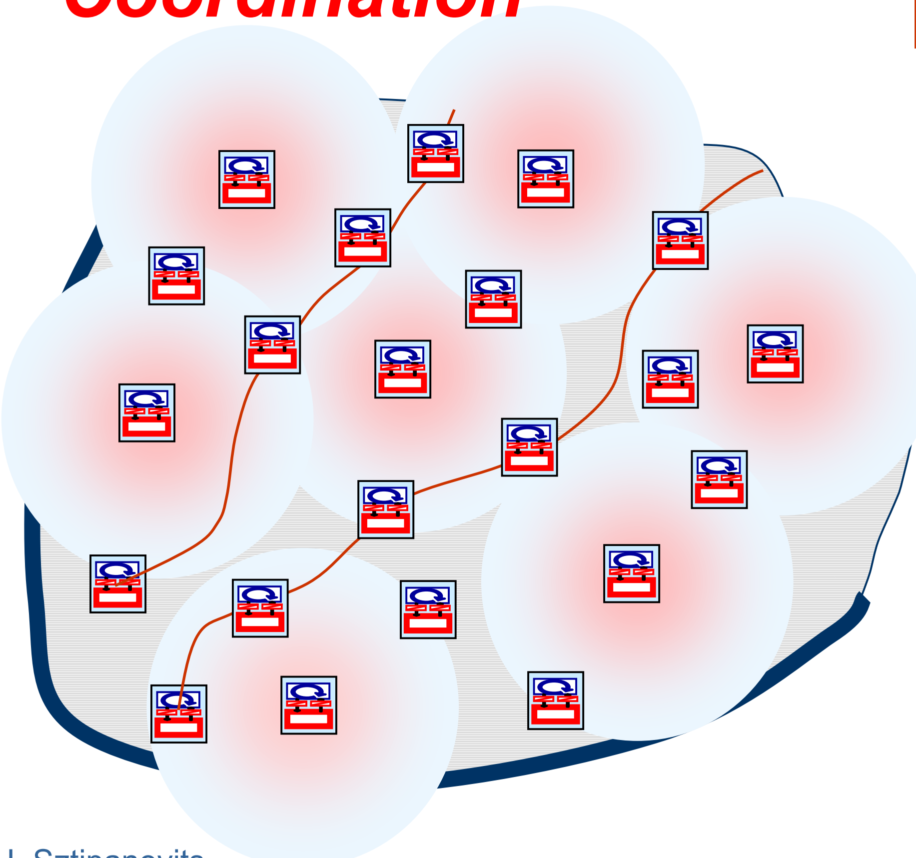
Theme 3: Dealing With Dynamic Structures

A new category of systems:

Embedding +

Distribution +

Coordination

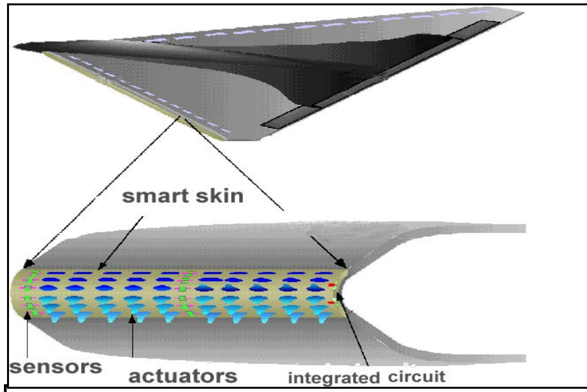


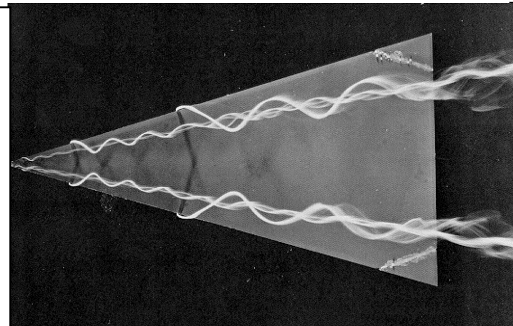
LARGE number of tightly integrated, spatially distributed physical and information system components with reconfigurable interconnection.

Why should we work on this?

- Tremendous progress in MEMS, photonics, communication technology: **we need to build systems now from these.**
- Identified applications with **very high ROI: strong application pull**
- **Almost total lack of design theory technology: the problem is extremely hard.**

Networked Embedded Systems: Examples

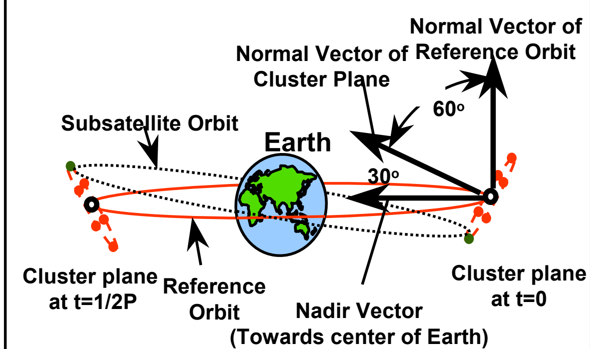


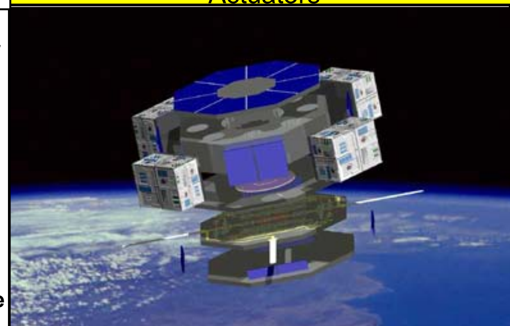


Vortex Control Using Distributed MEMS Actuators

MEMS Actuators for Vortex Control (UCLA, CalTech)

- Number of nodes: 10^4
- Loop frequency: 1 KHz
- Coordination frequency: 10Hz
- Geometric size: 30m



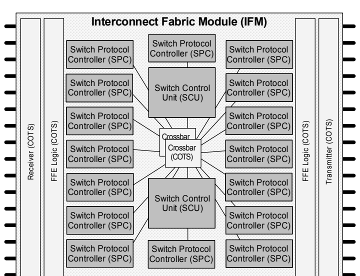


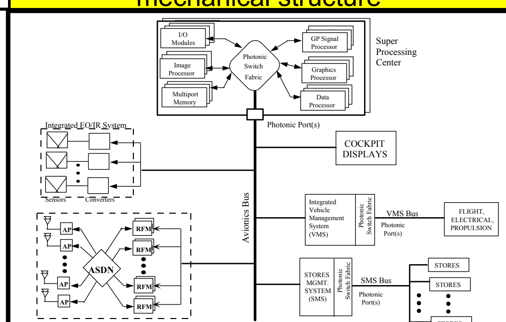
Information processing replaces mechanical structure

Pico Satellite Constellations (Aerospace Corporation)

- Number of nodes: 10^2 - 10^3
- Loop frequency: 1-2 KHz
- Coordination frequency: 1Hz
- Geometric size: 1-1000km

Key Integrating Element:
Interconnect Fabric Element (IFM)



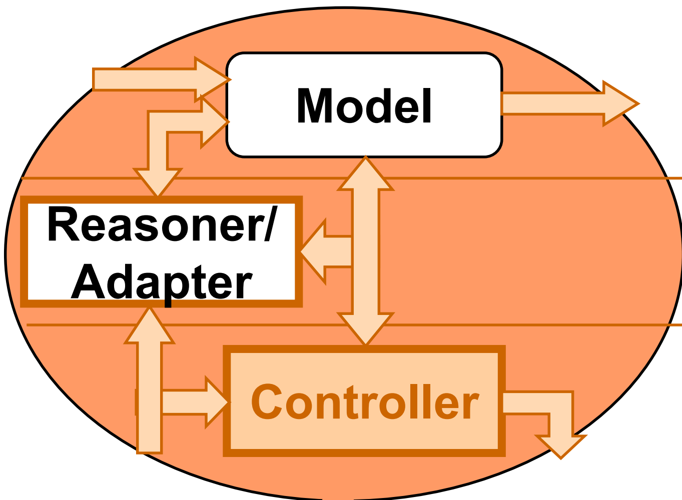


Scaleable Photonics Processing Unified Network

Unified Processing Network For Avionics

- Processing nodes: > 3*10^3
- Link Bandwidth: 2GHz
- Aggregate Bandwidth: >10^12
- Industry Standard Protocol

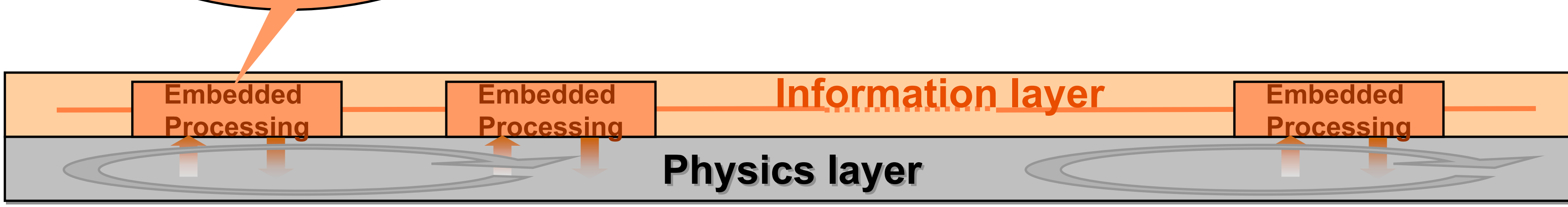
Need: Middleware for Coordination and Distribution



Model: Locally and globally relevant information for global coordination

Reasoner/Adapter: Adaptation of local structure and parameters, coordination

Controller: Discrete or hybrid control of local physics



Distribution:

- heterogeneous, simple components (10^2-10^5)
- changing interconnection topology
- **embedded synthesis** for dynamic distribution, reconfiguration

Coordination:

- global **coordination** of local interactions
- consistency of globally relevant information
- requirements are determined by locality of physics

DARPA Embedded Software Program Suite

1. Software Enabled Control
   FY99-03
2. Model-Based Integration of Embedded Software
   FY00-04
3. Program Composition of Embedded Software
   FY00-04
4. Networked Embedded Software Technology
   FY01-05

Future of Embedded Software

- One of the fundamentally new, tremendously expanding areas of computing.
- (a) No matter which walk of life you choose, you end up writing software…
  (b) No matter how great computer scientist you are - if you do embedded software – you will not get away without learning physics and engineering.
- Answering the challenges requires nothing less than the re-integration of physical and information sciences.

Thematic Areas for ITO